Cooking Up Extreme Matter

Creating Extreme Matter with One of the Most-intense Light Pulses on Earth

Extreme matter is usually a hot, dense plasma, ordinary matter broken down by extreme heat into a swirling soup of positively charged atomic nuclei (ions) and negatively charged electrons.

"One way to create extreme matter is to shine intense light—just a pulse of it—onto a solid target, usually a metal foil or wire, to quickly heat it up," says Montgomery. "Trident makes some of the most-intense light pulses on Earth."

In addition to being intense, the pulse must be extremely brief. Because hot plasmas disperse rapidly and lose energy quickly, mainly radiating it as ultraviolet light or even x-rays, the pulse must heat the matter much faster than the plasma disperses and cools through radiation. In a typical Trident experiment, a light pulse will turn a tiny bit of target material into a microplasma with a volume of 1 cubic millimeter (about the size of a large grain of salt) or less.

The light energy required to do that and the time in which the energy must be deposited in the target determine the light pulse's power, which is the energy of the pulse divided by its duration.

To produce 1 cubic millimeter of extreme matter requires about 1 trillion watts (a terawatt), equal to the combined power output of all the electrical plants in the United States. But don't worry about the lights dimming each time Trident spits out a light pulse. Trident packs the terawatts into the pulse by cramming a small amount of energy—about what's needed to light a 100-watt light bulb for a few seconds or so—into a very brief time. The longest pulse produced at the facility lasts for only a few tens of microseconds. Trident also produces pulses that pack 200 terawatts of power, more than enough to create some very extreme matter, but those pulses are even shorter—only half a trillionth of a second.

Moreover, Trident can provide its short pulses and long pulses simultaneously. "For example," Montgomery says, "a long pulse can be used to create extreme matter while a series of short pulses acts as a fast strobe light to photograph how the matter behaves. With two long-pulse beams and one short-pulse beam, as well as great versatility in being able to change the pulses' shapes in time, Trident is probably the most-flexible high-power-laser system in the world."

When focused onto a target, a Trident short pulse is also very small, with a diameter of 9.6 millionths of a meter (9.6 micrometers)—that's about the diameter of a red blood cell—and a length about equal to the thickness of a sheet of paper (about 150 micrometers). Squeezed into this tiny volume, the light can exert a pressure of billions of atmospheres. This "radiation pressure" can very effectively push a plasma's electrons around, a phenomenon scientists can exploit to spectacular effect.

The power, duration, and size of a Trident short pulse are typical of the short pulses produced at the handful of high-power-laser facilities that exist around the world. But Trident's short pulses contain more of the available light energy than other lasers in its class. The method used to generate powerful short pulses also produces a preceding jolt of light, a "prepulse," which hits a target before the short pulse does. However, because the short pulses at Trident and other high-power-laser facilities contain so much energy for their size, the premature arrival of even a tiny fraction of that energy can blast a target to smithereens before the short pulse arrives. For this reason, experiments with metal-foil targets thinner than 1 micrometer require as small a prepulse as possible.

At Trident, the prepulse value of the short pulses is less than one 10-billionth of the available light energy. That leaves nearly all of the energy—at least 99.99999999%—to be packed into the Trident short pulse. To put that in perspective, if the prepulse were a wave an eighth of an inch high, the short pulse would be at least 20,000 miles high. Trident's prepulse value is about 10,000 times smaller than those of the four other operational short-pulse lasers in Trident's energy class. No wonder Trident researchers can do experiments that cannot be done elsewhere!